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THE COLOR CURVE OF THE 12-INCH EQUATORIAL OF THE LICK OBSERVATORY

BY EDITH E. CUMMINGS AND PRISCILLA FAIRFIELD

In planning for a new spectrograph for the 12-inch refractor of the Lick Observatory, the first question was whether a correcting lens would be required. To decide this the color curve of the object glass must be known.

Accordingly a 1-prism spectrograph was assembled, adjusted and attached to the telescope. The spectrograph consists of two square wooden tubes, the larger one attached to the telescope, the smaller one sliding within this and bearing all the optical parts. The motion of this tube is effected by a rack and pinion; the amount of motion is gauged by a millimeter scale on the side of the tube. The slit mechanism is of the simplest form, consisting merely of two polished metal plates whose distance apart is varied by a double-motion screw. A window in the outer tube permits access to the slit. The collimator and camera lenses are of 2.0 inches and 2.06 inches aperture respectively, and their focal lengths are 32 inches and 12.4 inches. The collimator lens is corrected for $H\gamma$; the camera, for $H\delta$. The prism has a refracting angle of 60°; it is set for minimum deviation at $H\gamma$. The collimator tube and prism box are entirely of wood, and the camera tube is of brass. The frame into which the plate-holder slides can be tilted several degrees with respect to the axis of the camera.

We made observations of the color curve in two different ways—photographically by Vogel's method and visually by the Foucault method. These were employed during the same period and as far as possible on the same nights. The observations were taken at temperatures ranging from $+0^\circ.6$ to $+17^\circ.8$ C.

Vogel's method consists in opening the slit wide and using the star-image, instead of the slit, as the source, the photographic plate having first been put accurately in the conjugate "dust-line" focus of the collimator and camera lenses. For a given position of the slit only one region (or sometimes two) of the spectrum will be in focus on the plate. The resulting image will be a spindle-shaped figure, the nodes of which travel along the spectrum as the slit is moved up and down in the axis of the telescope.

Our first step was to take a series of sky plates with the slit narrowed until the dust-lines showed prominently. By varying the camera focal settings and the tilt of the plate-holder we found for each region of the spectrum the position of the plate where the slit, as shown by the dust-lines, was in focus. We found that the entire range of the spectrum from 3600 to 6800 angstroms could be put in the dust-line focus with only three changes in the position of the plate. These positions are:

for 3600—4308 A, camera setting $8^{mm}.8$, plate inclined 4° to the axis of the camera, the shorter wave-lengths having the longer focus;
4308—4861 A, camera setting $8^{mm}.8$, plate perpendicular to the axis of the camera;
4861—6800 A, camera setting $8^{mm}.0$, plate inclined 4° to the axis of the camera, the longer wave-lengths having the longer focus.

To record this last region we stained plates by the Wallace formula.[1]

The plate-holder used was so constructed that the plate could be moved laterally by means of an external screw; thus as many as ten exposures could be taken on a 7/8 by 3¼ inch plate. Our practice was to start with small scale readings, and to move the spectrograph down by intervals of 1 or 2^{mm} for the successive exposures. The exposures were started and stopped by means of a piece of cardboard interposed above the slit. Correct timing required much practice. With the bright stars used (*Vega*, *Rigel* and *Sirius*) a few seconds or sometimes a fraction of a second was sufficient to give the requisite density. The time had to be varied according to the particular portion of the spectrum, the ends requiring six to eight times as long as the central portion (4500 A). In case the plate received too short or too long an exposure the position of the node was not clearly defined. Care had to be taken lest a region of low sensitiveness be mistaken for a node. Since the position of these false nodes did not vary with changing collimator settings, the measurer, after a little practice, was able to detect them at once. We rejected all images which were not of the right intensity or too broad on account of poor seeing. On six different nights, from October 30 to December 11, 1918, we took plates, twenty-seven of which were finally used. The prominent hydrogen lines in the stars used furnished the dispersion curve from which the wave-lengths of the nodes were determined. From 3750 to 5000 A the nodes are well defined and easy to measure. Tho slightly different methods of measurement and reduction were employed by the two observers, our resulting photographic curves are practically identical. For wave-lengths longer than 5000 A the color curve is so flat that the method is no longer applicable, and we were forced to reject all plates of this region.

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[1] *Lick Obs. Bull.*, **5**, 151, 1909.

In the Foucault method the observer views the camera lens thru a small hole in a card placed in the focal plane of the lens. Thus only a very limited portion of the spectrum can be seen at one time. By flexing the telescope the observer moves the star image until it is cut off by one of the slit jaws, which thus acts as a knife-edge; as he views the camera lens he sees its illumination cut off from one side or the other. By moving the spectrograph up and down, the position is found where the slit is exactly at the focus of the large objective for the given wave-length. At this position the illumination of the lens is cut off instantly, or from both sides simultaneously.

We made a series of cards in each of which was a vertical slit about $\frac{1}{2}^{mm}$ wide. The positions of individual slits were different by about 1^{mm}; 16 of them gave points from 4100 to 6900 A at intervals of about 50 to 100 angstroms according to the part of the spectrum. On several nights we employed additional slits to get intermediate points. The cards were trimmed to fit the plate-holder frame, and care was taken to adjust them properly before making observations. To determine the mean wave-length of the light seen thru each slit, we observed the sky spectrum to find the particular slit thru which each of the Frauenhofer lines, G, b, E, D, C and B could be seen. These positions could be measured with ease to $0^{mm}.1$; from the resulting dispersion curve the wave-lengths admitted thru each slit of the series were read. To guard against a variation between day and night conditions we several times determined the wave-lengths on the Moon's spectrum, both before and after series of Foucault observations. We found that dispersion curves determined by day and by night could be used with equal degrees of accuracy.

TABLE I—NORMAL PLACES

Observer.... Method.... Mean Temp.	Cummings Visual 4°.6		Fairfield Visual 4°.6		Cgs. & Fd. Visual 4°.6		Cgs. & Fd. Phot. 4°.6		Cummings Visual 13°.6		Fairfield Visual 13°.6		Cgs. & Fd. Visual 13°.6		Cgs. & Fd. Phot. 13°.6	
Av. No. Pts. in a Normal.	9		8		19		3		5		3		8		3	
Normal No.	Coll. mm	λ	Coll. mm	λ	Coll. mm	λ	Coll. mm	λ	Coll. mm	λ	Coll. mm	λ	Coll. mm	λ	Coll. mm	λ
1	23.2	4211	22.6	4160	22.9	4208	37.0	3855	26.5	4130	22.0	4182	25.2	4152	43.0	3760
2	21.7	4264	21.0	4227	21.2	4246	34.0	3920	23.2	4213	19.0	4295	21.8	4226	40.0	3795
3	20.0	4282	19.7	4256	19.9	4272	32.0	3960	19.9	4324	17.8	4342	19.0	4302	39.5	3835
4	19.2	4327	19.0	4295	19.1	4315	30.0	3990	18.0	4362	16.3	4391	18.1	4359	38.3	3853
5	18.0	4368	18.1	4306	18.3	4333	28.0	4055	17.5	4411	15.7	4492	17.0	4417	37.7	3873
6	17.0	4398	17.1	4355	17.3	4365	27.0	4085	15.9	4500	14.2	4549	15.3	4502	36.3	3880
7	16.2	4479	15.7	4396	16.4	4412	26.0	4110	13.8	4610	13.0	4582	13.5	4630	35.7	3900
8	15.1	4527	14.9	4462	15.3	4477	25.0	4140	12.6	4716	12.2	4681	12.2	4700	34.7	3918
9	14.1	4568	13.9	4518	14.5	4523	24.0	4170	11.1	4818	11.1	4770	10.9	4802	34.0	3940
10	13.1	4629	13.2	4569	13.6	4586	23.0	4205	10.5	4922	10.5	4844	10.4	4914	33.0	3946
11	12.8	4699	12.2	4654	12.7	4651	21.7	4247	9.2	5050	10.0	4902	9.2	5048	32.0	3973
12	11.8	4718	11.3	4697	11.7	4691	19.0	4308	8.8	5151	9.3	5052	8.6	5190	31.3	3997
13	11.4	4798	10.8	4764	11.6	4766	17.7	4313	8.2	5214	8.3	5213	8.1	5276	30.3	3993
14	10.5	4830	9.9	4881	10.6	4810	17.3	4287	8.0	5328	7.7	5353	7.8	5411	29.7	4017
15	10.0	4901	8.7	4910	9.8	4895	16.0	4320	7.9	5458	7.7	5533	7.8	5583	28.7	4042
16	9.1	4942	8.5	5044	9.0	4954	16.0	4360	7.9	5612	7.5	5757	7.9	5766	28.0	4077
17	8.8	5036	8.0	5168	8.7	5056	15.2	4375	8.1	5772	8.0	5963	8.1	5934	27.0	4097
18	8.4	5078	7.5	5228	8.2	5114	14.0	4422	8.1	5916	8.3	6180	8.4	6159	26.0	4097
19	8.4	5153	7.4	5340	7.7	5188	13.0	4433	8.4	6150	8.5	6364	8.9	6410	24.3	4150
20	8.1	5197	7.3	5427	7.5	5271	13.8	4442	9.0	6430	9.1	6500	8.8	6670	25.3	4157
21	7.4	5211	6.9	5520	7.3	5345	12.0	4507	8.8	6450					23.7	4200
22	7.5	5297	7.0	5634	7.2	5446	12.0	4560	9.0	6840					22.7	4227
23	7.1	5340	7.4	5790	7.0	5520	11.0	4590							22.0	4277
24	7.2	5410	7.6	5852	7.2	5657	9.7	4678							20.5	4285
25	7.5	5497	6.9	5945	7.1	5776	9.0	4760							18.5	4300
26	7.0	5555	7.7	5970	7.3	5886	8.5	4940							17.5	4340
27	7.1	5683	7.6	6133	7.5	5950									16.0	4405
28	7.1	5740	7.8	6225	7.8	6108									15.0	4435
29	7.4	5882	8.0	6350	7.9	6227									14.0	4485
30	7.3	5915	8.5	6500	8.4	6404									13.0	4580
31	7.7	6055	8.7	6641	8.7	6571									12.0	4670
32	7.8	6150													9.5	4800
33	8.0	6222														
34	8.6	6298														
35	8.3	6415														
36	8.8	6473														
37	8.8	6578														

In Table I we have collected all the data obtained. The columns "Coll." give the position of the slit in terms of the scale on the moving tube; for brevity we called this simply the "collimator setting." Collimator settings increase numerically as the spectroscope is moved down (away from the 12-inch objective); when the setting is 6^{mm} the slit is 16.48 inches from the base plate of the telescope. A comparison of the different curves in Table I reveals several facts:

1. Altho the range of temperatures is small there is evidence of a temperature coefficient. At $13^\circ.6$ the focal length of the objective is $0^{\text{mm}}.7$ longer (on the average) than at $4^\circ.6$. This is expressed by the equation

$$R = R_0 + 0^{\text{mm}}.08\,(t - 9^\circ.1)$$

where R is the position of focus at temperature t, and R_0 is the focus at $9^\circ.1$ C. R_0 can be read from Figure 1, which is made by combining with equal weights the four curves: Visual $4^\circ.6$, Visual $13^\circ.6$, Photographic $4^\circ.6$, and Photographic $13^\circ.6$.

TABLE II

λ	Mean Phot. Curves ΔF, $13^\circ.6-4^\circ.6$	Mean Visual Curves $13^\circ.6-4^\circ.6$	Mean ΔF
	mm.	mm.	mm.
3900	+ 1.1		+ 1.1
4000	0.7		0.7
4100	0.6		0.6
4200	0.8	0.0	0.4
4300	1.8	0.0	0.9
4400	1.7	+ 0.6	1.2
4500	1.6	0.5	1.0
4600	1.7	0.4	1.0
4700	1.5	0.4	1.0
4800	1.0	0.4	0.7
4900		0.5	0.5
5000		0.6	0.6
5100		0.8	0.8
5200		0.8	0.8
5300		0.8	0.8
5400		0.8	0.8
5500		0.8	0.8
5600		0.8	0.8
5700		0.8	0.8
5800		0.8	0.8
5900		0.7	0.7
6000		0.7	0.7
6100		0.6	0.6
6200		0.5	0.5
6300		0.4	0.4
6400		0.3	0.3
6500		0.3	0.3
		Mean	+ 0.7 mm.

We plan to take further measures next summer at high temperatures. Comparison with the data obtained this winter should give a better value of the temperature coefficient.

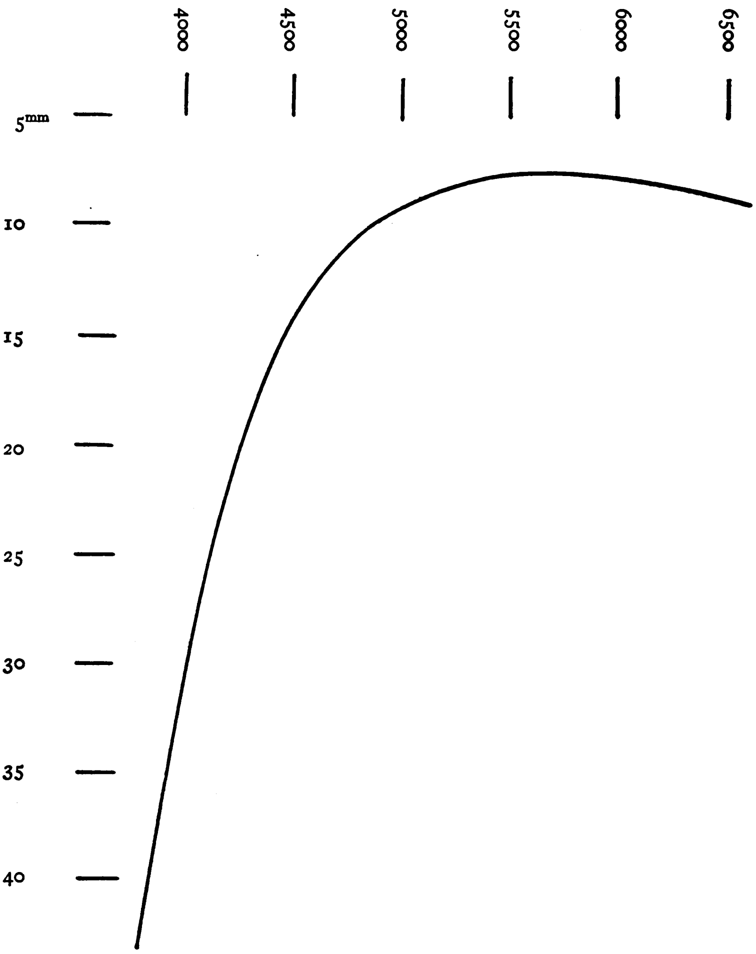

FIG. 1. Mean Color Curve at 9°.1 C.
12-inch Object Glass.

2. The visual measures show a personal equation between the two observers. Cummings's measures indicate a longer focal length than Fairfield's, the difference being a maximum for short wave-lengths.

TABLE III

	ΔF, Cummings—Fairfield		
λ	4°.6 mm.	13°.6 mm.	Mean ΔF mm.
4200	+ 1.6	+ 1.5	+ 1.6
4300	+ 1.2	+ 1.3	+ 1.2
4400	+ 1.4	+ 1.2	+ 1.3
4500	+ 1.4	+ 1.3	+ 1.4
4600	+ 1.2	+ 1.1	+ 1.2
4700	+ 1.0	+ 1.0	+ 1.0
4800	+ 0.7	+ 0.7	+ 0.7
4900	+ 0.6	+ 0.3	+ 0.4
5000	+ 0.3	0.0	+ 0.2
5100	+ 0.2	0.0	+ 0.1
5200	0.0	0.0	0.0
5300	0.0	+ 0.1	0.0
5400	0.0	+ 0.3	+ 0.2
5500	0.0	+ 0.4	+ 0.2
5600	0.0	+ 0.4	+ 0.2
5700	0.0	+ 0.4	+ 0.2
5800	0.0	+ 0.3	+ 0.2
5900	+ 0.1	+ 0.2	+ 0.2
6000	+ 0.2	+ 0.2	+ 0.2
6100	+ 0.2	0.0	+ 0.1
6200	+ 0.3	0.0	+ 0.2
6300	+ 0.3	0.0	+ 0.2
6400	+ 0.3	0.0	+ 0.2
6500	+ 0.3	0.0	+ 0.2

3. The visual and photographic curves differ in a peculiar manner which we are unable to explain. For wave-lengths 4400 to 4900 A the photographic method indicates a focal length about $1^{\mathrm{mm}}.8$ shorter than that determined by the visual method.

TABLE IV

	ΔF, Photographic—Visual		
λ	4°.6 mm.	13°.6 mm.	Mean Diff.
4200	0.0	+ 1.0	+ 0.5
4300	− 1.5	0.0	− 0.8
4400	− 2.1	− 1.7	− 1.9
4500	− 2.4	− 1.6	− 2.0
4600	− 2.4	− 1.5	− 2.0
4700	− 2.3	− 1.0	− 1.6
4800	− 2.0	− 1.0	− 1.5
4900	− 1.6		− 1.6

It was thought possible that spherical aberration in the 12-inch objective might be accountable for the difference Visual *minus* Photographic. To test this we cut two diaphragms, one covering the central 5-inch zone of the lens, the other leaving only this portion clear. On seven different nights we determined the color curve by the Foucault method for one zone and then for the other.

A slight difference was found; rays from the central zone have about $0^{\mathrm{mm}}.5$ longer focus than those from the outer zone. The mean differences from six pairs of curves for each observer are collected below.

TABLE V

ΔF, Outer Zone—Central Zone

λ	Mean Diff. mm.	λ	Mean Diff. mm.
4400	−0.2	5500	−0.6
4500	0.2	5600	0.6
4600	0.2	5700	0.6
4700	0.3	5800	0.6
4800	0.4	5900	0.6
4900	0.5	6000	0.6
5000	0.5	6100	0.7
5100	0.6	6200	0.6
5200	0.6	6300	0.6
5300	0.5	6400	0.6
5400	0.5		

Average $\Delta F = -0.5$ mm.

The individual measures for spherical aberration have been incorporated into the mean curves of Table I with weights proportional to the areas, i. e., weights 6, 5 and 1, respectively, for the full aperture, outer zone, and central zone. For the rays from the central zone the focus is much less definite than for the outer zone, an additional reason for giving those points small weight.

In order to find the relation between the collimator scale and the focal length of the telescope, we determined the position of the slit with respect to the optical center of the 12-inch objective. This was done by means of micrometer measures of the differences in declination between the following pairs of *Pleiades* stars:

TABLE VI

B.D.	Mag.		B.D.	Mag.	$\Delta\delta$
+23°557	4.0	and	+23°558	6.2	300″.23
23°558	6.2	and	23°562	7.8	400 .81
23°561	7.5	and	23°562	7.8	479 .21
23°563	7.2	and	23°569	7.5	493 .87

The differences in declination are the results of Dr. Elkin's measures[1] with the Yale heliometer, reduced to 1919.0.

We took 44 sets of measures, 22 for each observer, by the method of double distances; a set consists of 3 to 6 measures wires direct and 3 to 6 measures wires reversed. Each set gives a determination of the angular value of one revolution of the screw, the mean result being

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[1] R. G. Aitken, *The Binary Stars*, page 46, N. Y. 1918.

$$R = 14''.031 \pm 0''.0014$$

The focal length of the telescope was computed from the formula

$$F = \frac{B}{2} \cot \frac{R}{2}$$

where F is the focal length, B is the pitch of the micrometer screw, and R the angular value of one revolution; the micrometer screw has eighty threads to the inch. For the "visual rays" the focal length of the telescope at $10^\circ.0$ C is 15 feet 3.8 inches ±0.018 inches.[1] Referring to Figure I and the temperature equation and assuming that the light which was in focus was of wave-lengths 5300 to 6100 A we find that when the collimator setting is 8^{mm} the slit is 15 feet 3.8 inches from the optical center of the 12-inch lens. Collimator setting 8^{mm} puts the slit 15 feet 4.7 inches from the outer surface of the objective. This indicates that the optical center of the lens is 0.9 inches behind the front surface.

The aperture of the objective is 12.00 inches, so that the ratio $F{:}A$ is 15.4. Since $F{:}A$ for the collimator lens is 16, it is evident that our spectroscope has not utilized the outer ¼ inch zone of the objective.

In conclusion we wish to express our thanks to Director Campbell for kindly placing all facilities at our disposal; and to the Director, Dr. Aitken, Dr. Moore and Dr. Paddock for generous advice and assistance.

January 14, 1919.

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[1] In computing the probable error of F we assumed the relation $\frac{F}{\epsilon_0} = \frac{14.031}{0014}$